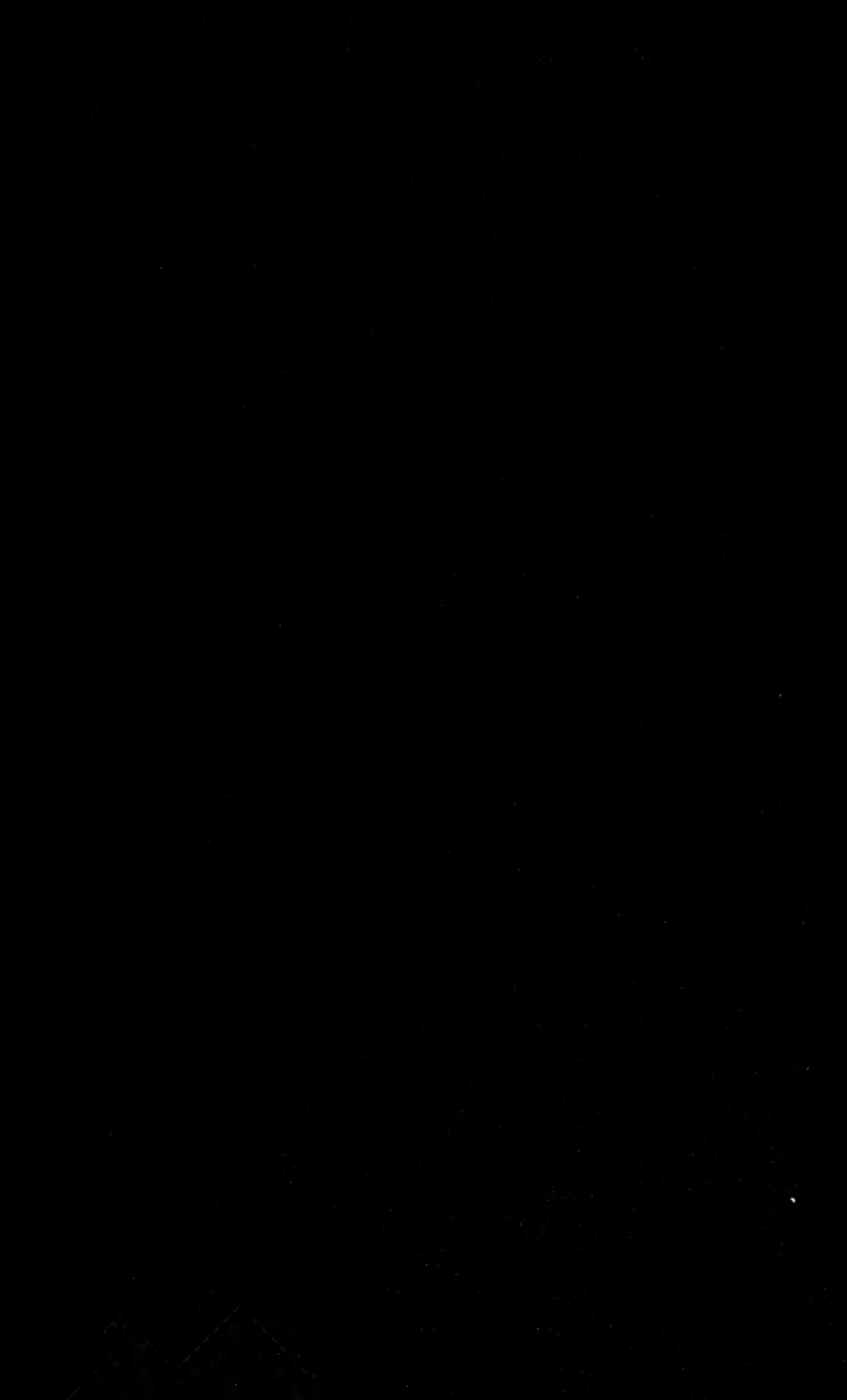

L161—O-1096

UNIVERSITY OF ILLINOIS

Agricultural Experiment Station.

URBANA, AUGUST, 1903.

BULLETIN No. 87.

THE STRUCTURE OF THE CORN KERNEL AND THE COMPOSITION OF ITS DIFFERENT PARTS.

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The possibility of selecting seed corn for improved chemical composition by a simple mechanical examination of sections of kernels (which any one can easily make with a pocket-knife) was clearly established by the experiments reported in Bulletin No. 55, "Improvement in the Chemical Composition of the Corn Kernel"; and the practical value of this method of selecting seed corn for high protein, high oil, or other desirable qualities has been fully confirmed by subsequent investigations and trials by the Experiment Station and by practical seed-corn breeders, as shown in Bulletin No. 82, "Methods of Corn Breeding."

A considerable amount of additional data relating to this matter has been accumulating with the progress of our experiments in corn breeding, and because of the very great importance of this subject to the corn growers and corn breeders of Illinois, and also because of the marked

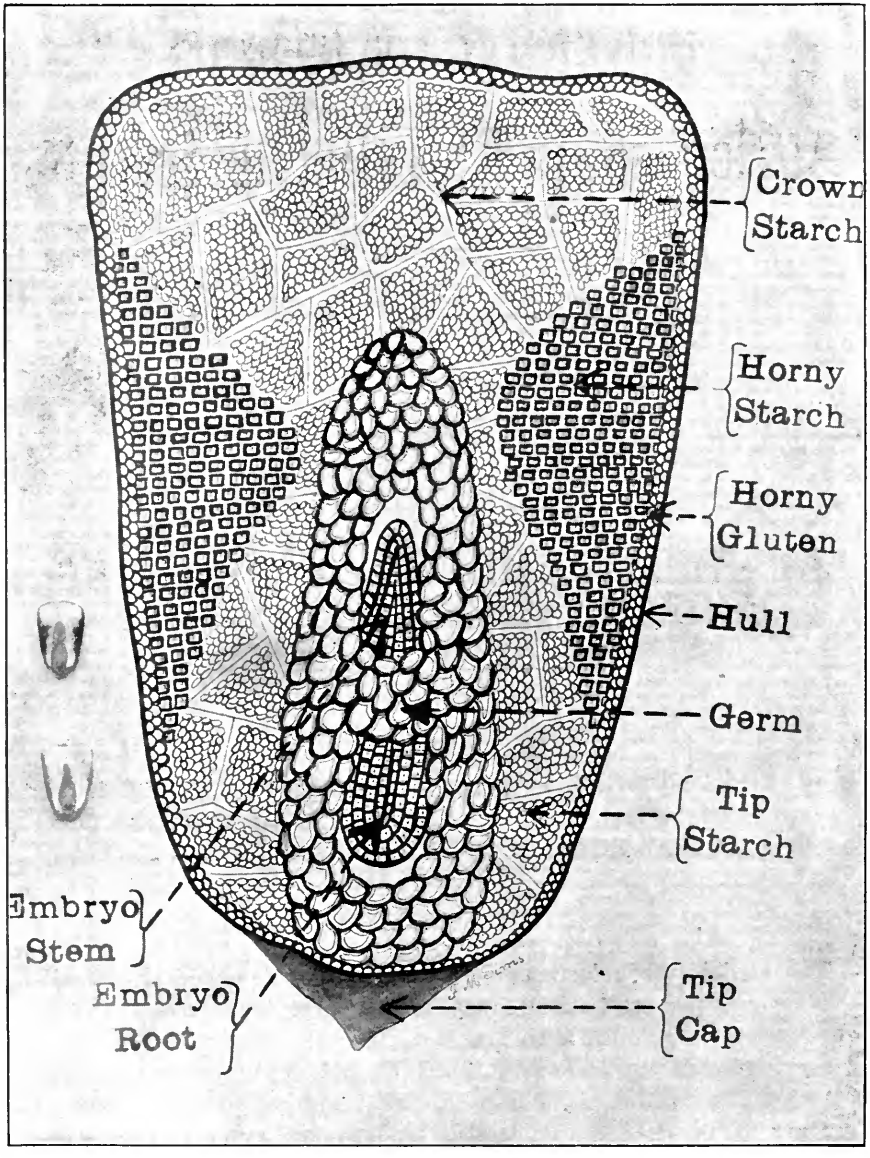

PLATE 1.—LOW-PROTEIN CORN KERNEL FROM DRAWING (SMALL KERNELS FROM PHOTOGRAPH).

interest which is manifested in this matter both by progressive, practical farmers and by scientific investigators, it has seemed advisable to publish in somewhat greater detail the results of our investigations along this line.

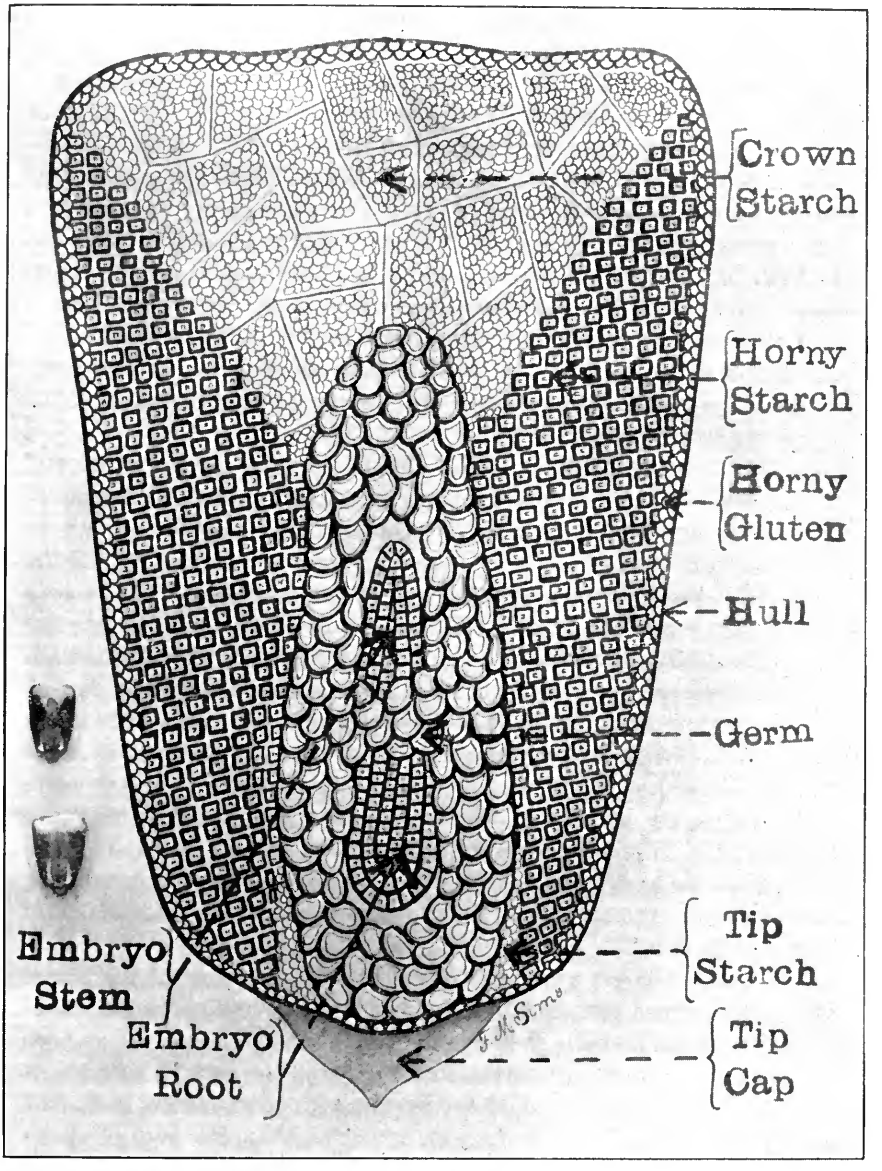

PLATE 2.—HIGH-PROTEIN CORN KERNEL FROM DRAWING (SMALL KERNELS FROM PHOTOGRAPH).

PARTS OF THE CORN KERNEL.

There are six distinctly different parts in a kernel of corn, as will be readily seen by reference to Plates 1 and 2.

1. TIP CAP.—This is a small cap covering the tip end of the kernel and serves as a protection to the end of the germ. It consists of material somewhat resembling the cob and occasionally in shelling corn the tip cap remains attached to the cob, leaving the tip end of the germ uncovered, but nearly always it remains on the kernel.

2. HULL.—This is the very thin outer covering of the kernel. It consists largely of carbohydrates, especially fiber or cellulose, although it also contains a small percentage of other constituents.

3. HORNY GLUTENOUS PART.—This part lies immediately underneath the hull. It constitutes a second covering of the kernel, usually much thicker than the hull. For short, it is called *horny gluten*, although it is, of course, not pure gluten. However, it is the richest in protein of any part of the corn kernel, as has been stated in bulletins already published by this station and previously by Doctor Voorhees, Director of the New Jersey Experiment Station.

4. HORNY STARCHY PART.—This part lies next to the horny gluten, on the back and sides of the kernel. For short, it is called *horny* starch, although it is not pure starch, as it contains considerable amounts of other constituents, especially of protein. In an examination of the kernel with the unaided eye the horny glutenous part and the horny starchy part are not readily distinguished from each other, the line between them being somewhat indefinite and indistinct. Considered both together these two parts constitute the horny part of the kernel.

5. WHITE STARCHY PART.—This part occupies the crown end of the kernel above the germ and it also nearly surrounds the germ toward the tip end of the kernel. For convenience this material is called white starch, although it is not pure starch as has been clearly shown in former publications. In some kernels the horny starch extends nearly or quite to the germ (near the middle of the kernel) and thus separates more or less completely the white starch into two parts which we call *crown starch* and *tip starch*.

6. GERM.—The germ occupies the center of the front of the kernel toward the tip end and usually extends about one-half or two-thirds of the length of the kernel. Within the body of the germ are the embryo stem pointing upward toward the crown end and the embryo root pointing downward toward the tip of the kernel, both of which are, of course, parts of the germ. These embryo parts within the germ may be easily seen by any one who will carefully shave off the front side of the germ from a kernel of corn. (See small photographic reproduction of sections of kernels of high and low protein corn in Plates 1 and 2.)

MECHANICAL SEPARATION OF THE DIFFERENT PARTS.

It is not a difficult matter to obtain very pure samples of each of the above-named parts of the corn kernel, although in making the separations there is of necessity some waste material consisting of a mixture of three different parts: namely, horny gluten, horny starch, and white starch.

By the use of a small sharp knife any one can make the following separations:

1. Tip cap.
2. Hull.
3. Horny gluten.
4. Horny starch.*
5a. Crown starch.
5b. Tip starch.
6. Germ.
7. Waste (mixed material).

In making these separations the kernels are first soaked in hot water for fifteen or twenty minutes.

The tip cap is then very easily and perfectly separated by simply cutting under one edge and then pulling it off.

The hull is separated without difficulty by peeling it off in strips. It is only necessary to use the knife to start the peeling at the tip end where the hull has been broken by removing the tip cap. With some care the hull can be completely peeled out of the dent in the corn.

The horny gluten is more easily distinguished after the hull is removed. It will be plainly seen that it covers the entire kernel, excepting possibly the exposed part of the germ. The horny gluten is removed by carefully shaving it off with a sharp knife. Adhering particles of starch can be more easily separated from the horny gluten after the shavings have been allowed to dry for some time. In scraping off these particles of horny starch or white starch adhering to the shavings, more or less horny gluten will also be scraped off, so that, while we are thus able to obtain a pure clean sample of the horny gluten, we also obtain some waste material, consisting of particles of horny gluten, horny starch, and white starch.

The germ is next removed, and with care this can be done very perfectly. If any particles of starch adhere to the germ they can easily be completely removed. After the tip cap, hull, horny gluten, and germ have been removed, the remainder of the kernel, consisting of the horny starch and white starch only, is allowed to dry, and the kernel is broken in two lengthwise.

*As used in this bulletin the term "starch" is employed in a technical or commercial sense, and not as the name of a definite chemical compound.

The crown starch is dug out with the knife as completely as possible without taking any of the horny starch.

The tip starch is next removed in the same manner as the crown starch.

The horny starch from each side usually remains in a solid piece. This is now carefully scraped to remove all adhering particles of white starch or horny gluten, the scrapings being carefully saved and added to the waste material.

By this method of separation we obtain eight different products, including the waste material, and seven of these products are pure samples of distinctly different parts of the corn kernel, excepting the crown starch and tip starch, both of which, of course, belong to the white starch; they are kept separate, however, because they are found in different places, frequently being entirely separated in the kernel, although more commonly there is some white starch continuous from crown to tip.

COMPOSITION OF THE DIFFERENT PARTS.

Table 1 shows the percentage of these eight different products, or parts, and the percentage composition of each part, also the percentage composition of the whole corn, for each of three different ears of corn. Ear No. 1 is corn of comparatively low* protein content (see foot-note). Ear No. 2 has about the usual protein content of ordinary corn. Ear No. 3 is high* protein corn (see foot-note). About 200 grams (nearly one-half pound) of kernels from each ear were separated into the different parts, and each part was then weighed and analyzed separately, another sample of the corn from each ear being analyzed to give the composition of the whole corn. (All results are given on the water-free basis.)

*It should be understood that Ear No. 1 (9.28 percent protein) and Ear No. 3 (12.85 percent protein) do not represent extremes in protein content; indeed, in our breeding of corn for low protein we have produced good ears containing less than 6.50 percent of protein, and in our high protein field we have produced corn containing over 16 percent of protein. In extremely low protein corn the percentage of horny part is very much less than in Ear No. 1, and in extremely high protein corn the tip white starch is frequently almost entirely wanting and the crown white starch very greatly reduced, both being replaced by the horny part, as shown in the drawings and also in the actual photographs of sections of kernels shown beside the drawings in Plates 1 and 2.

TABLE 1.—PERCENTAGE OF DIFFERENT PARTS AND PERCENTAGE COMPOSITION OF EACH PART.

Names of parts.	Percent of whole.	Composition of parts.			
		Protein, percent.	Oil, percent.	Ash, percent.	Carbohydrates, percent.
Ear No. 1 (low in protein).					
Tip caps	1.20	7.36	1.16	.91	90.57
Hulls	5.47	4.97	.92	.82	93.29
Horny gluten	7.75	19.21	4.00	.92	75.87
Horny starch	29.58	8.12	.16	.18	91.54
Crown starch	16.94	7.22	.19	.32	92.27
Tip starch	10.93	6.10	.29	.29	93.31
Germs	9.59	19.91	36.54	10.48	33.07
Mixed waste	18.53	9.90	1.06	.61	88.43
Whole corn	.....	9.28	4.20	1.41	85.11
Ear No. 2 (medium in protein).					
Tip caps	1.46	8.83	2.30	1.11	87.76
Hulls	5.93	3.96	.89	.79	94.36
Horny gluten	5.12	22.50	6.99	1.72	69.09
Horny starch	32.80	10.20	.24	.24	89.32
Crown starch	11.85	7.92	.17	.24	91.67
Tip starch	5.91	7.68	.39	.31	91.62
Germs	11.53	19.80	34.84	9.90	35.46
Mixed waste	25.40	11.10	1.23	.57	87.10
Whole corn	.....	10.95	4.33	1.55	83.17
Ear No. 3 (high in protein).					
Tip caps	1.62	4.64	1.99	1.87	91.50
Hulls	6.09	3.84	.76	1.10	94.30
Horny gluten	9.86	24.58	4.61	1.74	69.07
Horny starch	33.79	10.99	.22	.21	88.58
Crown starch	10.45	8.61	.52	.37	90.50
Tip starch	6.23	7.29	1.36	.60	90.75
Germs	11.93	19.56	33.71	10.00	36.73
Mixed waste	20.03	12.53	1.15	.61	85.71
Whole corn	.....	12.85	5.36	1.67	80.12

A careful study of Table 1 reveals some very interesting and useful facts regarding the structure of the corn kernel and the composition of the different parts. It is certainly an interesting fact that there are so

many different parts in a kernel of corn, and it is exceedingly useful to be able by a mechanical examination of corn not only to pick out high protein corn or high oil corn as one may desire, but even to separate the several distinctly different parts from one another by purely mechanical means—to separate, for example, the horny gluten, containing (in the high protein ear) nearly 25 percent of protein, and then the white starchy parts, with only 7 or 8 percent of protein; or the germs containing about 35 percent of oil and 10 percent of ash, and then the horny starchy part containing less than 0.25 percent of either oil or ash.

The hulls contain about 4 percent of protein and are clearly the poorest in protein of any part of the kernel, the next poorest being the tip caps and white starchy parts, containing about 7 or 8 percent, the tip starch being slightly poorer than the crown starch. The horny starch is richer in protein than the white starch, especially in the medium and high protein corn where the difference amounts to more than 2 percent, the horny starchy part containing from 10 to 11 percent of protein. The protein content of the germs is very uniform in the different ears, although the poorest germs are found in the high protein corn, and the richest in the low protein corn, the variation being from 19.56 to 19.91 percent. The horny gluten is the richest in protein of any part of the kernel in both ordinary and high protein corn, as was pointed out several years ago by Doctor Voorhees,* Director of the New Jersey Experiment Station, and as we have quoted in previous publications of the Illinois Experiment Station. In the high protein corn the protein content of the horny gluten amounts to 24.58 percent. In the low protein corn it is slightly less than that of the germ.

It is plainly seen that the oil in corn is very largely in the germ, although the horny gluten also contains a considerable percentage, the germ containing about 35 percent of oil and the horny gluten about 5 percent. Both the horny starch and white starch are exceedingly poor in oil, averaging about 0.25 percent, if we disregard the tip starch in Ear No. 3, which appears to have absorbed some oil directly from the germ which it adjoins and partially surrounds. The hulls contain slightly less than 1 percent of oil and the tip caps slightly more than 1 percent, and it is quite possible that this oil may have been obtained, in part at least, by absorption from the horny gluten and germ. Indeed, it seems highly probable that practically all of the true oil in the corn kernel is originally deposited in the germ and horny gluten, and that the small percentage or mere trace, which is found in the other parts is largely obtained by absorption. That such absorption actually does occur is definitely proven by the fact that the percentage of oil in hominy and hominy products increases with the age of the corn used in the milling. (Hominy

*New Jersey Agricultural Experiment Station Bulletin (1894), 105.

consists largely of the horny starch with more or less adhering white starch.)

It may be of interest to state in this connection that in 1866 Haberlandt* discovered with the microscope that the germ of the corn kernel contains a large amount of oil. He observed no oil in the remaining portions of the kernel. By chemical analysis Lenz* found, however, that after the germs were removed the remaining portion of the kernel contained 1.57 per cent of oil. These results were fully confirmed by Doctor Atwater† who found 1.63 per cent. of oil in the corn after removing the germs and adjoining material, although neither Lenz nor Atwater appear to have ascertained that the horny gluten (the aleurone layer) contains the chief percentage of oil outside of the germ.

By further reference to Table 1, it will be observed (1) that the germ contains about 10 percent of ash or mineral matter; (2), that this is about ten times the average percentage of ash contained in the other parts; and (3), that the percentage of ash in the different parts varies with the percentage of oil, to quite a noticeable degree.

Of course the percentage of carbohydrates (starch, cellulose, pentosans, etc.) varies inversely as the sum of the other constituents, being about 35 percent in the germ, 70 percent in the horny gluten, and from 90 to 95 percent in the other principal parts.

The marked degree of uniformity in the entire percentage composition of the germs from each of these three ears, whether low protein, medium protein, or high protein, seems especially noteworthy. The percentage of protein varies only from 19.56 to 19.91; the oil from 33.71 to 36.54; the ash from 9.90 to 10.48; and the carbohydrates from 33.07 to 36.73. It will also be noted that the percentages of both protein and oil are lower in the germs from high protein corn than in those from the low protein corn, although the differences are not marked.

MATHEMATICAL DISTRIBUTION OF WASTE.

It will be borne in mind that in making the mechanical separations, in order to obtain each of the seven different parts in pure condition, unmixed with any other part, there was necessarily some waste product. This waste substance amounted to about 20 per cent of the whole. As has already been explained, this mixed waste material consists of only three distinctly different parts—horny gluten, horny starch, and white starch (from crown and tip), the other three parts—tip caps, hulls, and germs, being easily separated completely and in pure form.

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*Allgemeine land—und forstwirtschaftliche Zeitung (1866), 257; Jahresbericht (Hoffman) über die Agricultur-Chemie (1866), 9, 106.

†Thesis, Yale College (1869); American Journal of Science and Arts (1869) (2), 48, 352.

By a simple computation the mixed waste material can be distributed among the respective parts of which it is composed, provided we may be allowed to make the assumption (which is approximately the truth) that the horny starch and white starch are present in the waste material in the same proportions as they are in the pure separated portions. Any error which might be introduced by following this assumption would have but little effect because the composition of the horny starch and white starch are not very markedly different (the protein differs by 2 to 3 percent); and also because the total amount of waste material to be distributed is only from one-third to one-half the sum of the separated horny starch and white starch.

It will be observed (see Table 1) that the mixed waste is always richer in protein than the horny starch, thus showing that, besides horny starch and white starch, it also contains more or less horny gluten, which, of course, we know to be the fact.

If in 100 grams of corn we let

x equal the number of grams of tip starch,
Bx equal the number of grams of crown starch,
Cx equal the number of grams of horny starch,
y equal the number of grams of horny gluten, and
S equal the sum of these four parts, then

(1) $x + Bx + Cx + y = S$

Now if we let

a equal the per cent of protein in the tip starch,
b equal the per cent of protein in the crown starch,
c equal the per cent of protein in the horny starch,
d equal the per cent of protein in the horny gluten, and
s equal the number of grams of protein in all of these four parts, then

(2) $ax + bBx + cCx + dy = s$

Thus we have two equations with which to solve for x and y, which are the only unknown quantities, B and C being factors which can be obtained by dividing the percents of separated crown starch and horny starch, respectively, by that of tip starch, and S being the sum of the separated tip starch, crown starch, horny starch, horny gluten and mixed waste, as given in Table 1; and a, b, c, d, being the respective percentages of protein in the four separated materials, tip starch, crown starch, horny starch, and horny gluten, and s being the total number of grams of protein contained in these four separated parts and in the mixed waste, all of which data are also given in Table 1.

PHYSICAL COMPOSITION OF THE CORN KERNEL.

From the above computations we obtain the results given in Table 2, which gives the total percentages of each of the seven different parts con-

tained in the corn kernel (counting crown starch and tip starch as two parts), and with no waste material.

TABLE 2.—TOTAL PERCENTAGES OF THE DIFFERENT PARTS OF THE CORN KERNEL.

Name of parts.	Ear No. 1, (low protein).	Ear No. 2, (medium protein).	Ear No. 3, (high protein).
Tip caps	1.20	1.46	1.62
Hulls	5.47	5.93	6.09
Horny gluten	11.61	8.51	13.32
Horny starch	37.15	47.08	44.89
Crown starch	21.26	17.01	13.88
Tip starch	13.71	8.48	6.28
Germs	9.59	11.53	11.93
Total	99.99	100.00	100.01

It will be observed that the percentages of horny gluten, horny starch, and germs are noticeably higher in the high protein corn than in the low protein corn; while the opposite is true with the white starch, the percentages of crown starch and tip starch being markedly higher in the low protein corn than they are in the high protein corn. It is noteworthy that the horny gluten in high protein corn not only contains a higher percentage of protein than the germs, but that the proportion of horny gluten in the kernel equals or exceeds that of the germs. The only discrepancies appearing in Table 2 are the low percentage of horny gluten and the high percentage of horny starch in Ear No. 2. Otherwise the percentages of parts in the medium protein ear are always intermediate between those in the other two ears, as would be expected. Even these discrepancies disappear if the two horny parts be added together and considered as one part, as is done in the practical work of selecting seed corn for higher protein content by mechanical examination, as will be seen by referring to Table 3.

TABLE 3.—PERCENTAGES OF THE DIFFERENT PARTS OF THE CORN KERNEL AS COMMONLY OBSERVED IN MECHANICAL EXAMINATION FOR SEED CORN SELECTION.

Names of parts.	Ear No. 1, (low protein).	Ear No. 2, (medium protein).	Ear No. 3, (high protein).	Average percent.
Tip caps	1.20	1.46	1.62	1.43
Hulls	5.47	5.93	6.09	5.83
Horny part	48.76	55.59	58.21	54.19
White starch	34.96	25.49	22.16	27.54
Germs	9.59	11.53	11.93	11.02
Total	99.98	100.00	100.01	100.00

In this table the crown starch and tip starch are also added together and the sum recorded as white starch. The increase in the amount of horny part (from 48.76 to 58.21 percent), and the decrease in white starch (from 34.96 to 22.16 percent) as we pass from the low protein to the high protein corn, is plainly apparent.

DISTRIBUTION OF CHEMICAL CONSTITUENTS.

Table 4 shows the location or complete distribution of the chemical constituents among the seven different physical parts of the corn kernel. In other words, this table represents the separation of 100 grams (or 100 pounds) of corn into seven different structural or physical parts, and the subsequent division of each of these parts into the four chemical constituents, protein, oil, ash, and carbohydrates.

The complete data shown in Table 4 are presented especially for the benefit of farmers who are corn breeders, and also for the benefit of the manufacturers of corn products. The agreement between the sum of the separate determinations and the direct determinations of the same constituent in the whole corn is very satisfactory, considering that these results are obtained by computation from the analyses of nine different materials, including the whole corn. The greatest difference is well within the limit of unavoidable error in sampling and analytical determinations. A careful study of this table will reveal some interesting and valuable facts. For example, it will be seen that in 100 pounds of the low protein corn the horny gluten contains only 2.23 pounds of protein; while 3.27 pounds of protein are contained in the horny gluten in 100 pounds of the high protein corn. Again, in 100 pounds of the low protein corn the horny starch contains only 3.02 pounds of protein; while 4.93 pounds of protein are contained in the horny starch in 100 pounds of the high protein corn.

On the other hand, in 100 pounds of the low protein corn the crown starch and tip starch contain 1.53 and .84 pounds of protein, respectively; while 1.20 and .60 are the respective amounts contained in the corresponding parts of the high protein corn.

If we add together the horny parts and then add together the crown starch and tip starch, as is done in the practical selection of seed corn by mechanical examination, we obtain the results shown in Table 5.

TABLE 4.—PHYSICAL AND CHEMICAL DISTRIBUTION OF 100 GRAMS (OR 100 POUNDS) OF CORN.

Names of parts.	Physical distribution (grams or pounds).	Chemical distribution.			
		Protein, (grams or pounds).	Oil, (grams or pounds).	Ash, (grams or pounds).	Carbohydrates, (grams or pounds).
Ear No. 1 (low in protein).					
Tip caps	1.20	.09	.01	.01	1.09
Hulls	5.47	.27	.05	.04	5.10
Horny gluten	11.61	2.23	.46	.11	8.81
Horny starch	37.15	3.02	.06	.07	34.01
Crown starch	21.26	1.53	.04	.07	19.62
Tip starch	13.71	.84	.04	.04	12.79
Germs	9.59	1.91	3.50	1.01	3.17
Total	99.99	9.89	4.16	1.35	84.59
Whole corn		9.28	4.20	1.41	85.11
Ear No. 2 (medium in protein).					
Tip caps	1.46	.13	.03	.02	1.28
Hulls	5.93	.23	.05	.05	5.60
Horny gluten	8.51	1.89	.59	.15	5.88
Horny starch	47.08	4.80	.11	.11	42.05
Crown starch	17.01	1.35	.03	.04	15.59
Tip starch	8.48	.65	.03	.03	7.77
Germs	11.53	2.28	4.02	1.14	4.09
Total	100.00	11.33	4.86	1.54	82.26
Whole corn	.....	10.95	4.33	1.55	83.17
Ear No. 3 (high in protein).					
Tip caps	1.62	.08	.03	.03	1.48
Hulls	6.09	.23	.05	.07	5.74
Horny gluten	13.32	3.27	.61	.23	9.20
Horny starch	44.89	4.93	.10	.09	39.76
Crown starch	13.88	1.20	.07	.05	12.56
Tip starch	8.28	.60	.11	.05	7.51
Germs	11.93	2.33	4.02	1.19	4.38
Total	100.01	12.64	4.99	1.71	80.63
Whole corn	.....	12.85	5.36	1.67	80.12

TABLE 5.—POUNDS OF PROTEIN IN 100 POUNDS OF CORN.

Names of parts.	Low protein corn.	Medium protein corn.	High protein corn.
In tip caps	.09	.13	.08
In hulls	.27	.23	.23
In horny part	5.25	6.69	8.20
In white starch	2.37	2.00	1.80
In germs	1.91	2.28	2.33
Total	9.89	11.33	12.64

It will be observed that the increase in protein in high protein corn over that in low protein corn occurs almost entirely in the horny part of the corn kernel. As indicated in previous bulletins there is also a slight increase in protein in the germ, although this is quite insignificant as compared with the increase in the horny part. In passing from low protein corn to high protein corn, there is an appreciable decrease in the amount of protein contained in the white starch. Of course this is due to the marked decrease in the actual amount of white starch in high protein corn. Indeed, this decrease in the quantity of white starch is even more marked than would appear from Table 5, because the white starch in the high protein corn is actually richer in protein than that in low protein corn, as would be expected and as is shown in Table 1.

The data given in Table 5 strongly confirm the results which we have already obtained in practical experience in corn breeding. For example, we have been breeding both high protein corn and low protein corn for the past seven years. In the high protein corn we find that the proportion of horny part has increased very markedly, while the white starchy part has markedly decreased. In the low protein corn the opposite is true, the horny part having decreased and the white starchy part having markedly increased, in proportion.

By computation from the data given in Table 4, we have constructed Table 6, which shows the percentage distribution of the different chemical constituents among the several physical parts of the corn kernel.

It will be seen that as an average about 22 percent of the total protein is contained in the horny gluten, nearly 40 percent in the horny starch, and nearly 20 percent in the germ, thus these three parts contain about 80 percent of the total protein in the kernel.

The germ contains from 80 to 84 percent of the oil, while all other parts combined contain only 15 to 20 percent of the total oil in the kernel. Based upon this fact is the method for selecting high oil or low oil seed corn by mechanical examination, the ears whose kernels show a large proportion of germ being high oil corn and those with small germs

TABLE 6.—PERCENTAGE DISTRIBUTION OF CHEMICAL CONSTITUENTS AMONG PHYSICAL PARTS.

Ear No. 1 (low in protein).

Names of parts.	Percent of total protein.	Percent of total oil.	Percent of total ash.	Percent of total carbohydrates.
In tip caps	.89	.33	.81	1 29
In hull	2.75	1.21	3.34	6.03
In horny gluten	22.56	11.13	7.96	10.41
In horny starch	30.51	1.43	4.98	40.22
In crown starch	15.52	.97	5.07	23.18
In tip starch	8.46	.95	2.96	15.12
In germs	19.31	83.99	74.87	3.75
Total	100.00	100.01	99.99	100.00

Ear No. 2 (medium in protein).

In tip caps	1.14	.69	1.06	1.56
In hull	2.07	1.08	3.06	6.80
In horny gluten	16.67	12.21	9.56	7.15
In horny starch	42.36	2.32	7.38	51.12
In crown starch	11.88	.59	2.67	18.96
In tip starch	5.75	.68	1.72	9.45
In germs	20.14	82.43	74.55	4.97
Total	100.01	100.00	100.00	100.01

Ear No. 3 (high in protein).

In tip caps	.59	.65	1.76	1.84
In hull	1.85	.93	3.90	7.12
In horny gluten	25.88	12.29	13.49	11.41
In horny starch	39.00	1.98	5.49	49.31
In crown starch	9.45	1.44	2.99	15.58
In tip starch	4.77	2.25	2.89	9.32
In germs	18.45	80.46	69.46	5.43
Total	99.99	100.00	99.98	100.01

low oil corn. (See Plate 4.) About 12 percent of the total oil is contained in the horny gluten, leaving only about 5 percent of the oil distributed among the remaining five physical parts, and, as stated above, more or less of this small amount is undoubtedly absorbed from the contiguous germ or horny gluten.

It will be noted that the ash is closely associated with the oil, nearly 75 percent of the total ash being contained in the germ, and about 10 percent in the horny gluten, as an average.

Table 7 shows, for direct comparison, the percentage distribution of the protein among the different physical parts, in each ear, the two horny parts, and also the two white starchy parts, being combined, as in Table 5.

TABLE 7.—DISTRIBUTION OF 100 GRAMS (OR 100 POUNDS) OF PROTEIN AMONG THE PHYSICAL PARTS AS OBSERVED IN MECHANICAL EXAMINATION.

Names of parts.	Low protein corn.	Medium protein corn.	High protein corn.
In tip caps	.89	1.14	.59
In hulls	2.75	2.07	1.85
In horny part	53.07	59.03	64.88
In white starch	23.98	17.63	14.22
In germs	19.31	20.14	18.45
Total	100.00	100.01	99.99

Table 7 illustrates very plainly the fact that, as we pass from low protein corn to high protein corn, the protein decreases in the white starchy part and increases in the horny part; in other words, in breeding corn for high protein, we decrease the white starchy part, which is comparatively poor in protein, and increase the horny part, which averages very much richer in protein, the horny starch containing 2 to 3 percent more protein than the white starch, and the horny gluten being richer in protein than any other part of the kernel. As a rule, in breeding for high protein there is also a slight increase in the proportion of germ, which, being rich in protein, adds somewhat to the increase in protein.

MECHANICAL METHODS OF SELECTING SEED CORN FOR IMPROVEMENT IN COMPOSITION.

As has already been shown in our Bulletin No. 82 "Methods of Corn Breeding," we have found it entirely feasible and practical to select seed corn of higher protein content by a simple mechanical examination of a few kernels from each ear. With some care any farmer or corn grower can learn to pick out high protein seed corn by dissecting and examining a few kernels from each ear (by means of a pocket-knife), selecting for high protein seed the ears whose kernels show a large proportion of horny

part, and rejecting those showing a small proportion of horny part. (See Plate 3; also Plates 1 and 2.)

HIGH PROTEIN KERNELS
(Much horny part;
little white starch).

LOW PROTEIN KERNELS
(Little horny part;
much white starch).

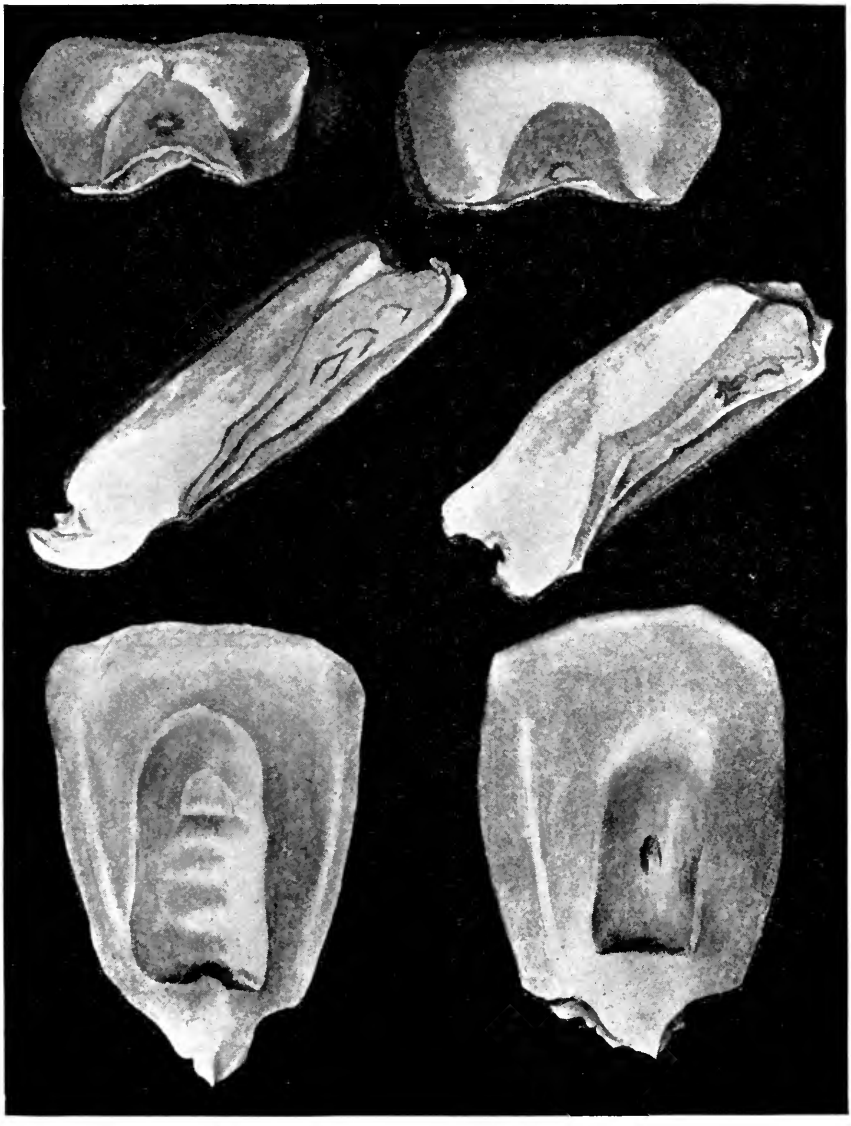

PLATE 3.

This method is already in use by practical corn breeders, and with a very satisfactory degree of success. For example, in selecting seed corn by this method Mr. Ralph Allen, of Tazewell County, obtained seed ears for the year 1902, which were 1.46 percent higher in protein than the rejected ears from the same lot, and for this season (1903) his selected seed ears contain 1.58 percent protein more than the ears which he has rejected. In other words, his selected seed corn is richer by 1.58 pounds of protein per 100 pounds of corn than that rejected.

The method proposed some years ago by Professor Willard, Director of the Kansas Agricultural Experiment Station, of picking out high protein seed by simply selecting for large germs enables one, as a rule, to make some gain in protein, but the gain is very much greater when the proportion of horny part is considered. In fact, from our own experience we find that the selection for a large proportion of horny part is a very much more trustworthy index than the size of the germ, in securing high protein seed, and we often find corn with large germs which is actually low in protein, because of a small percentage of protein in the remainder of the kernel. The fact that only 20 percent of the total protein of the kernel is obtained in the germ (as shown in Table 7) is evidence of the uncertainty of obtaining high protein seed corn, and of the improbability of making any very considerable gain in protein, by this method of selection. This difficulty was well understood by Professor Willard, as will be seen in the following quotation from the Kansas Experiment Station Bulletin No. 107, page 63.

"There are undoubtedly great differences in the protein content of the part of the kernel exclusive of the germ, and it is conceivable and not improbable, that a large germ, though in itself tending to produce high protein content might be overcome by the low protein of the remainder of the kernel."*

Of course, if one picks out corn with large germs and at the same time, either consciously or unconsciously, selects those ears whose kernels contain a large proportion of horny part, he may make considerable gain in protein, but in such case the gain should not be attributed solely to the large germs.

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* ***Protein*** is substituted for *nitrogen* in this quotation.

HIGH OIL KERNELS (Large germs).

LOW OIL KERNELS (Small germs).

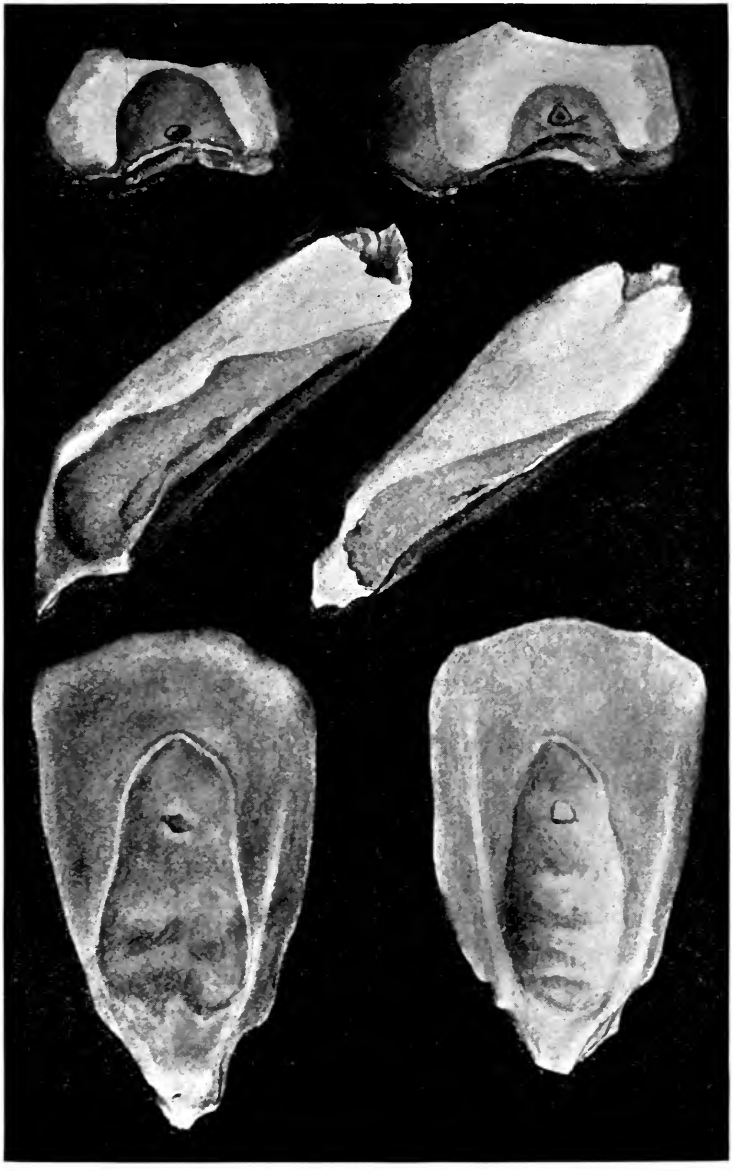

PLATE 4.

The method of selecting seed corn for high oil content on the basis of large germs (see Plate 4) is certainly well founded, because of the fact that more than 80 percent of the total oil of the kernel is contained in the germ.

THE CORRELATION OF SOME PHYSICAL PARTS AND CHEMICAL CONSTITUENTS OF THE CORN KERNEL.

As was clearly shown in our Bulletin No. 55, there is usually a marked correlation between the percentage of germ and the percentage of oil in the corn kernel, as will be seen from the following summary of 100 *separate determinations* reported in that bulletin:

TABLE NO. 8.—CORRELATION BETWEEN GERM AND OIL IN CORN KERNELS.

Number of determinations.	Small germ corn.		Large germ corn.	
	Germ, percent.	Oil, percent.	Germ, percent.	Oil, percent.
10	**9.10**	3.58	**14.11**	6.49
10	**8.56**	3.22	**12.40**	6.71
10	**8.28**	3.64	**12.01**	6.08
10	**8.73**	3.32	**13.30**	5.82
10	**9.82**	4.30	**11.06**	5.21
General average	**8.90**	3.61	**12.57**	6.06

While there is, of course, some variability due in part to the different percentages of oil in germs from different kernels (especially in kernels from different ears) and in part to the different percentages of oil in the horny gluten (and to some extent in other parts) from different ears (see Table 2), nevertheless it will be observed that there is a marked correlation between the percentage of germ and the percentage of oil in the corn kernel. In other words, the percentage of oil varies with the percentage of germ. It will be observed, however, that a high percentage of germ is accompanied by a still higher proportionate percentage of oil, indicating that increased proportion of germ in the kernel is due to an increase in the quantity of oil more largely than of the remainder of the germ.

CORRELATION BETWEEN OIL AND PROTEIN.

That there is a marked correlation between the percentages of germ and oil in the corn kernel is certainly well established; consequently, if the proportion of germ were a reliable index to the relative protein content of the kernel, there would, of course, be some marked correlation between the percentages of oil and protein in corn.

In Table 1 of Bulletin No. 55 are recorded the proximate analyses of 163 different ears of corn. Table 9 is derived from that data, and shows the percentages of oil and protein contained in the ten ears which are lowest in oil and in the ten ears which are highest in oil, the analyses being arranged in the descending order for protein.

The correlation between oil and protein is certainly very slight. In the low oil corn the oil varies from only 3.84 to 4.08 percent, while the protein varies from 9.08 to 12.96 percent. In the high oil corn the oil

varies only from 5.46 to 6.02, while the protein varies from 9.58 to 13.87 percent, making a difference of 4.29 percent protein between these extreme ears, while the difference in oil is only .09 percent between the same ears. The average percentages of oil in these two lots of corn vary from 3.99 to 5.64 percent, while the corresponding averages for protein are 11.02 and 11.19, thus showing very little correlation between the percentages of oil and protein in the corn kernel.

TABLE 9.—CORRELATION BETWEEN OIL AND PROTEIN IN THE CORN KERNEL.

Low oil corn.		High oil corn.	
Oil, percent.	Protein, percent.	Oil, percent.	Protein, percent.
3.97	12.96	5.72	13.87
3.99	12.28	5.51	13.10
4.03	11.71	5.61	12.09
4.07	11.49	5.75	11.18
3.84	11.29	5.65	10.82
4.08	11.29	5.51	10 49
3.94	10.97	5.46	10.32
4.01	9.68	5.51	10.23
3.95	9.44	6.02	10.18
4.05	9.08	5.63	9.58
Averages3.99	11.02	5.64	11.19

Table 10 is also derived from Table 1 of Bulletin No. 55, and is similar to Table 9, except that the analyses of the ten ears lowest in protein and of the ten ears highest in protein are chosen. This shows the reverse correlation; that is, between protein and oil. Of course, the results should be practically the same as shown in Table 9, the chief value of Table 10 being that it uses almost an entirely different set of analyses, and consequently gives a duplicate illustration of the lack of correlation between these two constituents.

TABLE 10.—CORRELATION BETWEEN PROTEIN AND OIL IN THE CORN KERNEL.

Low protein corn.		High protein corn.	
Protein, percent.	Oil, percent.	Protein, percent.	Oil, percent.
9.31	4.96	13.87	5.72
8.40	4.91	13.10	5.51
8.38	4.88	12.68	5.29
9.31	4.82	12.81	5.21
8.25	4.81	12.63	5.15
9.22	4.60	13.06	4.93
9.15	4.55	12.57	4.82
9.30	4.38	12.79	4.25
9.12	4.10	12.76	4.10
9.08	4.05	12.96	3.97
Averages...8.95	4.61	12.92	4.90

It will be observed that, although the averages for protein vary from 8.95 to 12.92 percent, the averages for oil vary only from 4.61 to 4.90 percent. These averages indicate only a slight correlation between protein and oil, and the analyses of the individual ears show that even this correlation is by no means constant.

In connection with some investigations relative to heredity Professor Frank Smith of this University, has prepared correlation tables (see Tables 11 and 12) from the 163 analyses of individual ears of corn recorded in Table 1 of Bulletin No. 55. Table 11 shows the correlation between

TABLE 11.—ONE HUNDRED SIXTY-THREE EARS OF CORN GROUPED ACCORDING TO PERCENTAGES OF PROTEIN AND CARBOHYDRATES.

Carbohydrates percent.	Protein, percent.													Total No. of ears.
	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	
79													1	1
79.5														
80											1			1
80.5										1	2			3
81									1	3				4
81.5							1		2	7	3			13
82							2	5	13					20
82.5					1	3	7	12	3	1				27
83					2	7	16	7						32
83.5				2	7	9	4	1						23
84				3	7	5	1							16
84.5			1	8	2									11
85			1	5										6
85.5	1	2	2	1										6
Total No. of ears.	1	2	4	19	19	24	31	25	19	12	6		1	163

The correlation of high protein with low carbohydrates and *vice versa* equals 90.05 per cent.

protein and carbohydrates, the entire 163 ears of corn being grouped according to the percentage of protein and carbodydrates which they contain. This table well illustrates what is meant by a high degree of correlation. With an increasing protein percentage there is a decreasing percentage of carbohydrates, and there are no marked exceptions to this rule. Note, for example, that there is one ear containing 14 percent of

protein, but that this ear contains only 79 percent of carbohydrates, being the highest in protein and also the lowest in carbohydrates of the 163 ears. There are nineteen ears containing only 12 percent of protein, but none of these nineteen ears contains less than 81 percent of carbohydrates; thirteen of them contain 82 percent of carbohydrates, while five others are within one-half percent of that amount. One ear contains only 8 percent of protein, but this ear contains 85.5 percent of carbohydrates, being both the lowest in protein and the highest in carbohydrates of the 163 ears. It will be observed that of the 163 ears, several groups fall in the squares representing low protein (8 to 10 percent) and high carbohydrates (84 to 85.5 percent); also that many ears fall in the squares representing high protein (12 to 14 percent) and low carbohydrates (80 to 82 percent); so that, including the ears with medium content of protein and carbohydrates, we find that the group numbers of 163 ears fall almost in a straight line extending from the lower left-hand corner to the upper right-hand corner of the table. It will be seen that no ears whatever fall in the squares representing high protein and high carbohydrates, or in those representing low protein and low carbohydrates. By mathematical computation Professor Smith has found that we have in this table 90.05 percent of a perfect correlation.

TABLE 12.—ONE HUNDRED SIXTY-THREE EARS OF CORN GROUPED ACCORDING TO PERCENTAGES OF PROTEIN AND OIL.

Oil, percent.	Protein, percent.													Total No. of ears.
	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	
3.8								1						1
4.0			2	2			2	3	1	1	1			12
4.2				3	2	3	3	2	3		2			18
4.4				3	4	2	7	3	2					21
4.6			2	1	1	8	5	8	4	3				32
4.8	1	1		5	6	3	7	2	4	5				34
5.0		1		2	1	3	3	5	4		1			20
5.2				2	3	2	2	1		3	1			14
5.4						2								2
5.6				1	1	1	1		1		1			6
5.8							1						1	2
6.0					1									1
Total No. of ears.	1	2	4	19	19	24	31	25	19	12	6		1	163

The correlation of high protein with high oil and of low protein with low oil equals 3.81 percent.

Table 12 shows the degree of correlation which exists between oil and protein. It will be seen that there is no such grouping as in Table 11. In other words, there is no marked correlation between the oil and protein in corn. Some ears are rich in one of these constituents and poor in the other; other ears are rich in both, and still others are poor in both, so that the grouping of the numbers of ears according to the percentages of oil and protein which they contain resembles a circle much more nearly than a straight line. By computation it is found that there is a slight tendency for the protein to increase with increasing oil content, but the degree of correlation amounts to only 3.81 percent of a perfect correlation.

All of the above data tend to prove that, as the percentage of protein increases in corn the starch decreases, while the oil remains almost unchanged; and that we may increase or decrease the percentage of oil or of germ in corn without markedly affecting the percentage of protein. This was the conclusion drawn when the above-mentioned 163 ears of corn were analyzed more than six years ago. The different strains of corn which we have finally produced in our regular corn breeding work furnish us excellent material for ascertaining what effect is produced upon the oil content of corn by breeding for a higher or lower protein content; and, *vice versa*, what effect is produced upon the protein content by breeding for a higher or lower oil content.

In 1900 we planted ten field rows (called the "mixed plot") with two kinds of corn in every row, one kind having been bred for four years for high oil content, the other (originally from the same variety and stock) having been bred during the same four years for low oil content. These two kinds of seed were planted in every row and in fact in every hill, the low oil kernels and the high oil kernels in the same hill—just far enough apart so that the identity of the individual plants could be known as they grew during the season. The corn from each of the ten rows was harvested in two lots, one lot being corn from high oil seed and the other lot being from low oil seed. The two lots from each row were kept separate, the one being labeled as corn from the "high oil side" of the row and the other from the "low oil side."

The percentages of oil and of protein contained in these different lots of corn are shown in Table 13.

These data are considered very reliable, both kinds of corn having been grown during the same season and in exactly the same soil and each individual sample whose composition is shown in Table 13 being a composite sample representing many ears. The average difference in oil content between the high oil side and the low oil side is 1.97 percent of oil, while the average difference in protein is 0.18 percent. Considering that the percentage of protein in the corn is twice as large as the percentage of oil, it will be seen that there is less than 5 percent of a perfect correlation between the oil and protein.

TABLE 13.—OIL AND PROTEIN IN CORN HARVESTED FROM THE "MIXED OIL" PLOT IN 1900.

Row No.	Low oil side.		High oil side.	
	Oil, percent.	Protein, percent.	Oil, percent.	Protein, percent.
1	3.93	10.07	5.61	10.06
2	3.78	9.26	5.74	9.05
3	3.73	10.21	5.88	9.12
4	3.75	8.47	5.99	9.65
5	3.89	9.39	5.71	10.08
6	3.80	9.77	5.91	10.23
7	3.60	9.80	5.60	9.91
8	3.58	9.65	5.84	10.32
9	4.22	9.18	5.68	9.15
10	3.27	9.26	5.82	9.32
Average	3.81	9.51	5.78	9.69

COMPOSITION OF PEDIGREED CORN.

In order that it might be shown with even more absolute certainty which physical part of the corn kernel should be increased in order to increase the protein content, or the oil content, etc., forty ears of corn were selected from the 1902 crop from our oldest breeding plots, ten ears being taken from each of four different strains, namely:

"Illinois" High Protein Corn.

"Illinois" Low Protein Corn.

"Illinois" High Oil Corn.

"Illinois" Low Oil Corn.

each of which represents the seventh generation of pedigreed corn, bred as indicated by the name. Twenty-five average kernels were taken from each of these forty ears, the germs separated from the remainder of the kernel and both parts (that is, germs and endosperms*) analyzed separately, for each ear, another sample of the corn from each ear also being analyzed to show the composition of the whole corn. The tabular statements show the results obtained.

By referring to Tables 14 and 15 it will be seen that the protein content of the low protein ears varies from 6.36 to 7.09 percent. with an average of 6.71 percent, while the protein content of the high protein ears varies from 13.98 to 15.01, with an average of 14.44 percent. The average oil content of the low protein corn is 4.21 percent and of the high protein ears 4.93 percent. The general averages indicate a slight correlation between oil and protein; however, there are several of the high protein ears which contain less oil than some of the low protein ears, thus showing that such correlation is not constant.

*As here used the term endosperm includes all parts of the kernel except the germ.

TABLE 14.—CHEMICAL COMPOSITION OF TEN EARS OF "ILLINOIS" LOW PROTEIN CORN.

Ear No.	Protein, percent.	Oil, percent.	Ash, percent.	Carbohydrates, percent.
4276	6.98	4.69	1.43	86.90
4281	6.60	4.21	1.33	87.86
4286	6.87	4.16	1.19	87.78
4287	6.37	3.90	1.40	88.33
4295	6.46	4.14	1.15	88.25
4313	7.01	4.13	1.27	87.59
4321	7.09	3.84	1.46	87.61
4328	6.36	4.05	1.43	88.16
4346	6.89	4.33	1.45	87.33
4368	6.48	4.67	1.56	87.29
Average	6.71	4.21	1.37	87.71

TABLE 15.—CHEMICAL COMPOSITION OF TEN EARS OF "ILLINOIS" HIGH PROTEIN CORN.

Ear No.	Protein, percent.	Oil, percent.	Ash, percent.	Carbohydrates, percent.
4174	14.70	5.87	1.48	77.95
4189	14.74	4.46	1.70	79.10
4202	14.21	4.54	1.50	79.75
4212	14.61	4.57	1.66	79.16
4218	14.37	4.61	1.63	79.39
4227	14.03	5.26	1.54	79.17
4242	14.28	5.33	1.51	78.88
4244	14.49	4.71	1.57	79.23
4253	15.01	5.01	1.38	78.60
4265	13.98	4.96	1.67	79.39
Average	14.44	4.93	1.56	79.06

Table 16 shows the percentages of protein and of germ in both the low protein and high protein ears.

TABLE 16.—PROTEIN AND GERM IN LOW PROTEIN AND HIGH PROTEIN CORN.

Low protein corn.			High protein corn.		
Ear No.	Protein, percent.	Germ, percent.	Ear No.	Protein, percent.	Germ, percent.
4276	**6.98**	9.52	4174	**14.70**	13.31
4281	**6.60**	8.81	4189	**14.74**	9.51
4286	**6.87**	8.42	4202	**14.21**	11.44
4287	**6.37**	9.53	4212	**14.61**	10.92
4295	**6.46**	7.95	4218	**14.37**	11.64
4313	**7.01**	8.98	4227	**14.03**	11.15
4321	**7.09**	10.30	4242	**14.28**	13.21
4328	**6.36**	8.88	4244	**14.49**	11.22
4346	**6.89**	10.14	4253	**15.01**	9.82
4368	**6.48**	10.79	4265	**13.98**	12.14
Average ...	**6.71**	9.33	Average ..	**14.44**	11.44

Here again we see a slight correlation between the average percentages of protein and germ in the corn kernel, although there are noteworthy discrepancies. Thus we have an ear containing 6.37 percent of protein and 9.53 percent of germ, while another ear contains 14.74 percent of protein and 9.51 percent of germ. In other words, the two ears contain practically the same percentage of germ, although one of them contains more than twice as much protein as the other. One of the lowest protein ears (6.48) contains 10.79 percent of germ, while the highest protein ear (15.01 percent) contains only 9.82 percent of germ.

Attention is called to the fact that in selecting seed corn by chemical analysis for high protein there is a tendency to increase not only the horny starchy part (which contains more total protein than any other part of the corn kernel), but also to increase both the horny gluten and the germ, both of which, although small in amount are rich in protein; and consequently there is a slight tendency for the oil to be increased, not only in the germ, but also in the horny gluten (aleurone layer), which it will be remembered is also quite rich in oil. This is the evident explanation as to why there is a slightly higher degree of correlation between oil and protein in our pedigreed strains of corn than there is in ordinary corn which has not been so bred.

Tables 17 and 18 show the percentage composition of the low oil and high oil ears.

TABLE 17.—CHEMICAL COMPOSITION OF TEN EARS OF "ILLINOIS" LOW OIL CORN.

Ear No.	Protein, percent.	Oil, percent.	Ash, percent.	Carbohydrates, percent.
4474	9.40	2.68	1.45	86.47
4486	9.16	2 65	1.64	86.55
4491	9.49	2.60	1.29	86.62
4495	9.57	2.59	1.41	86.43
4509	8.96	2.53	1.36	87.15
4512	10.64	2.45	1.46	85.45
4521	9.97	2.12	1.42	86.49
4537	10.89	2.40	1.54	85.17
4548	9.77	2.54	1.36	86.33
4555	11.92	2.65	1.42	84.01
Average	9.98	2.52	1.44	86.07

The average for the low oil corn is 2.52 percent of oil and 9.98 percent of protein, while the high oil contains 7.00 percent of oil and 11.31 percent of protein. In other words, the high oil corn contains almost three times as much oil as the low oil corn, but is less than one-seventh richer in protein, showing only slight correlation between oil and protein, and with several ears no correlation whatever exists. For example, we have one ear with 10.89 percent of protein and 2.40 percent of oil and another ear with 10.79 percent of protein and 7.01 percent of oil, the protein

being practically equal, while the one ear contains nearly three times as much oil as the other. Again the low oil ear No. 4555 (2.65 percent of oil) contains 11.92 percent of protein, or .61 percent more than the average of all of the high oil ears.

TABLE 18.—CHEMICAL COMPOSITION OF TEN EARS OF "ILLINOIS" HIGH OIL CORN.

Ear No.	Protein, percent.	Oil, percent.	Ash, percent.	Carbohydrates, percent.
4374	11.26	**7.10**	1.64	80.00
4411	10.79	**7.01**	1.40	80.80
4412	9.58	**6.87**	1.58	81.97
4417	10.33	**7.01**	1.66	81.00
4421	12.55	**7.02**	1.53	78.90
4423	11.66	**6.95**	1.56	79.83
4436	11.47	**7.17**	1.59	79.77
4441	12.94	**7.37**	1.57	78.12
4448	11.75	**6.78**	1.52	79.95
4462	10.76	**6.74**	1.48	81.02
Average	11.31	**7.00**	1.55	80.14

TABLE 19.—OIL AND GERM IN LOW OIL AND HIGH OIL CORN.

Low oil corn.			High oil corn.		
Ear No.	Oil, percent.	Germ, percent.	Ear No.	Oil, percent.	Germ, percent.
4474	**2.68**	8.05	4374	**7.10**	12.90
4486	**2.65**	8.13	4411	**7.01**	12.73
4491	**2.60**	7.92	4412	**6.87**	13.73
4495	**2.59**	7.39	4417	**7.01**	14.50
4509	**2.53**	7.06	4421	**7.02**	14.65
4512	**2.45**	7.89	4423	**6.95**	13.83
4521	**2.12**	7.13	4436	**7.17**	14.10
4537	**2.40**	7.57	4441	**7.37**	14.53
4548	**2.54**	7.83	4448	**6.78**	14.35
4555	**2.65**	8.47	4462	**6.74**	13.03
Average...	**2.52**	7.74	Average ..	**7.00**	13.84

Table 19, giving the percentages of oil and germ in the low oil and high oil corn, shows a very marked correlation between oil and germ. The ten low oil ears contain from 2.12 to 2.68 percent of oil (average 2.52) and from 7.06 to 8.47 percent of germ (average 7.74), while the ten high oil ears contain from 6.74 to 7.37 percent of oil (average 7.00), and from 12.73 to 14.65 percent of germ (average 13.84). There is no overlapping and the correlation is very distinct. Every low oil ear contains a small percentage of germ and every high oil ear a high percentage of germ. Attention is called to the fact that the high oil corn is even richer in oil than would be indicated by the high percentage of germ as compared with the percentage of oil and germ in the low oil corn, indicating that the breeding for high oil has not only increased the oil by in-

creasing the percentage of germ (which contains most of the oil), but that the percentage of oil in the germ itself has increased. (Of course there is also an increase in the percentage of oil in the horny glutenous part.) Similarly the percentage of oil has decreased even more rapidly than the percentage of germ in the low oil corn. These results are very apparent in the data shown in Table 20.

EFFECT OF BREEDING ON COMPOSITION OF GERMS AND ENDOSPERMS.

As already explained, ten ears were selected from each of the four different strains of corn (low protein, high protein, low oil, and high oil), and twenty-five kernels were taken from each of these forty ears, the germ being separated from the remainder of the kernel, which we call the endosperm. After the percentage of germ was determined from each individual ear, the germs from each lot of ten ears were put together to make two samples, each sample representing five ears. The endosperms were likewise put together, so that we have duplicate samples of both germs and endosperms for each of the four different strains. These samples were analyzed chemically and the results are given in Table 20.

TABLE 20.—CHEMICAL COMPOSITION OF GERMS AND ENDOSPERMS FROM LOW PROTEIN AND HIGH PROTEIN CORN AND FROM LOW OIL AND HIGH OIL CORN.

Kind of corn.	Part of kernel.	Protein, percent.	Oil, percent.	Ash, percent.	Carbohydrates, percent.
Low protein	Germs	**18.05**	33.59	10.19	38.17
		17.96	34.60	10.16	37.28
High protein	Germs	**20.85**	34.99	10.12	34.04
		21.65	36.02	10.07	32.26
Low oil	Germs	21.70	**25.01**	13.13	40.16
		21.71	**24.62**	13.36	40.31
High oil	Germs	17.55	**41.76**	8.75	31.94
		17.84	**41.75**	8.81	31.60
Low protein	Endosperms	**5.69**	.83	.43	93.05
		5.68	.91	.43	92.98
High protein	Endosperms	**13.67**	.76	.36	85.21
		13.92	.72	.41	84.95
Low oil	Endosperms	9.13	.52	.47	89.88
		9.14	.51	.43	89.92
High oil	Endosperms	10.62	**1.07**	.36	87.95
		10.10	**1.24**	.39	88.27

These results show in a very striking manner the effect of breeding in changing the composition of the different physical parts of the kernel. Thus the germs from the low oil corn contain about 25 percent of oil, while those from the high oil corn contain nearly 42 percent of oil. As

stated above, breeding to change the oil content not only changes the percentage of germ, but it also changes the percentage of oil in the germ. It should also be noted that endosperms from the high oil corn contain more than twice as much oil as those from the low oil corn, although the percentage of oil in the endosperm is very small even in the high oil corn, and this oil is largely contained in the horny gluten.

Perhaps the most marked and valuable results are shown in the percentages of protein contained in the endosperms from low protein and high protein corn; the endosperms from the low protein corn contain less than 6 percent of protein, while those from the high protein corn contain nearly 14 percent of protein. These results, in connection with others which we have given, would seem to prove very conclusively that to select high protein seed corn by mechanical examination we should select principally for a large proportion of the more nitrogenous part of the endosperm; that is, the horny part. To select only for large germs will have only a slight effect upon the protein content of the corn, although it will produce a rapid and marked increase in the oil content.

Referring again to Table 20, it will be seen that the endosperms from the high oil corn contain about one percent more protein than those from the low oil corn. On the other hand, the germs from high oil corn contain less protein (17.7 percent) than those from low oil corn (21.7 percent), the difference being 4 percent protein in favor of the low oil corn.

These results were to be expected even from a study of the analyses of the 163 ears reported in Bulletin No. 55, in 1899, which showed that large germs were naturally even richer in oil than the size of the germs would indicate, and that there is but very slight correlation between oil and protein, the increased oil tending to decrease the percentage, though not the actual amount of protein in the germ. It will be seen from Tables 19 and 20 that the high oil corn contains nearly twice as much germ as the low oil corn, and that the germs from high oil corn are more than one and one-half times richer in oil than the germs from the low oil corn; but that, although the high oil germs contain a larger total amount of protein because of their increased size), they are really considerably poorer in percentage of protein than the low oil germs.

It is perhaps worth while to consider the evident fact that, even if the protein should increase in the germ in the same proportion as the oil (which is not the case), we should need to increase the oil two pounds for every one pound increase in protein obtained, if we depend upon the method of picking our high protein seed corn by selecting for large germs. In other words, to increase the protein in corn from 10 percent to 15 percent by this method, would require the oil in the corn to be increased from 5 percent to 15 percent.

Although we do not assume to say what should be the percentage of oil in corn for feeding purposes, we do take the liberty of raising the ques-

tion whether the popular opinion that the oil in corn should be increased for feeding purposes may not be erroneous. Certainly the investigations of Lehmann in Germany and of Shutt in Canada have indicated very strongly that corn is already too rich in oil to be suitable as a foodstuff for bacon hogs. It may also be called to mind that some other excellent foodstuffs, such as oats, bran, barley, red clover and alfalfa, contain less than half as much oil as is already contained in ordinary corn.

Attention is called to the fact that although the physical parts of the corn kernel which contain nearly all of the oil (namely the germ and the horny gluten) also contain most of the ash, yet a high percentage of ash in the germs is associated with a low percentage of oil, and *vice versa*, indicating that the ash content of the germ (which includes the major part of the ash of the entire kernel) bears a more constant relation to the oil-free material in the germ than to the whole germ. By computation we find that the oil-free germs contain the percentages of ash given in Table 21 (assuming the oil to contain no ash, which is approximately correct*).

TABLE 21.—PERCENTAGE OF ASH IN GERMS.

	In fresh germs.	In oil-free germs.
From low protein corn	10.19 10.16	15.34 15.54
From high protein corn	10.12 10.07	15.57 15.74
From low oil corn	13.13 13.36	17.51 17.72
From high oil corn	8.75 8.81	15.02 15.12

Breeding for high or low protein produces no marked effect upon the ash content or the oil content of either the germs or the endosperms, and only slightly influences the protein content of the germs. (The low protein germs contain about 18 percent of protein and the high protein germs about 21 percent.) The results show that such breeding produces exceedingly marked effects upon the protein content of the endosperms, the low protein endosperms containing less than 6 percent and the high protein endosperms nearly 14 percent of protein. In this connection it is well to remember that the corn kernel usually contains only about 11 percent of germ, while the endosperm amounts to about 89 percent of the kernel. The significance of this becomes more readily apparent by an examination of Table 22, which shows where the protein actually exists in 100 pounds of corn.

*Actual determinations of the ash in corn oil have shown that the oil contains only 0.2 per cent of ash.

TABLE 22.—PROTEIN IN 100 POUNDS OF CORN.

Names of parts.	Low protein corn.			High protein corn.			Difference.
	Percent of corn.	Percent of protein.	Pounds of protein.	Percent of corn.	Percent of protein.	Pounds of protein.	Pounds of protein.
In germs	9.33	18.01	**1.68**	11.44	21.25	**2.43**	.75
In endosperms	90.67	5.69	**5.16**	88.56	13.80	**12.22**	7.06

We thus find as a result of corn breeding that in the seventh generation we have a maximum difference of only .75 pound of protein in the germs from 100 pounds of low protein and high protein corn, while in the endosperms from these two kinds of corn we have a difference of 7.06 pounds of protein, in 100 pounds of corn. In other words, in changing the protein content of corn the effect produced in the endosperms amounts to almost ten times the effect produced in the germs.

THE COMPOSITION OF HOMINY MILL PRODUCTS.

Besides the investigations which we have carried on along this particular line in connection with our work of corn breeding, we have also made some study of factory products, especially the products from hominy mills, which make use of immense quantities of corn.

In the regular process of milling corn, a very large number of separations are made and several distinctly different final products are obtained, some of which are composed almost entirely of certain distinct physical parts of the corn kernel. The following is a brief and very general description of the usual process of corn milling:

The whole corn is somewhat softened by steaming and is then run through a hulling machine, which not only removes the hull, but loosens the germ and breaks off the horny gluten and more or less white starch. The dust or pulverized material coming from the hulling machine consists largely of white starch and horny gluten. The hulls and germs are each separated but not in very pure condition, leaving what is termed hominy, which consists chiefly of the horny starchy part of the kernel, with more or less adhering white starch.

The product which is known as grits is made from the hominy and consists of the horny starchy part separated in very pure form. In making grits the coarse hominy is run through a grinding machine and reduced to a coarse powder which may be termed coarse grits, much of the adhering white starch being rubbed off from the horny starch in this process. The coarse grits are then run through one or two more grinding machines, until the horny starch is reduced to a rather fine powder, which may be termed fine grits. This material consists of the horny starch in very pure condition. After each grinding the fine dust consisting largely

of the white starch is separated from the grits and goes into the product known as corn flour.

In addition to the corn flour thus regularly separated and handled in considerable quantities, there is constantly produced a small amount of what is termed "break" flour. This is an exceedingly fine dust also produced in the process of breaking the corn particles in the grinding machines which reduce the hominy to grits. The break flour is carried from the machine by an air current through conduits and finally collected. This is another very pure form of the white starch.

Thus, in the regular milling process there are two physical parts of the corn kernel separated in very pure form: namely, horny starch (fine grits) and white starch (break flour or corn flour) and two other distinct parts which are separated somewhat less perfectly, the hulls and the germs.

By the courtesy of the manager of the American Hominy Company's Mills at Decatur we were allowed to collect representative samples of these different products for analysis. The composition of these products is given in Table 23, and it will be found interesting to compare these results with the composition of the same products, or parts, which were obtained by exact hand separation, as given in Table 1. For convenience in comparison Table 23 also shows the composition of these parts as obtained from Ear No. 1 (Table 1), which is very similar to the corn which was being used in the mill at the time the samples were taken. This was fairly representative of the ordinary white corn grown in 1902, nearly all of which was abnormally low in protein, owing to seasonal influences.

TABLE 23.—COMPOSITION OF PARTS OF THE CORN KERNEL SEPARATED BY HOMINY MILL AND BY HAND.

Names of parts.	Methods of separation.	Protein, percent.	Oil, percent.	Ash, percent.	Carbohydrates, percent.
Hulls	By mill	6.85	2.94	1.11	89.10
Hulls	By hand	**4.97**	**.92**	**.82**	**93.29**
Horny starch (fine grits)	By mill	8.46	.44	.26	90.84
Horny starch	By hand	**8.12**	**.16**	**.18**	**91.54**
White starch (corn flour*)	By mill	5.91	1.63	.49	91.97
White starch (break flour)	By mill	5.88	2.04	.68	91.40
White starch (from tip)	By hand	**6.10**	**.29**	**.29**	**93.31**
Germs	By mill	15.84	21.26	7.41	55.49
Germs	By hand	**19.91**	**36.54**	**10.48**	**33.07**
Whole corn	Mill sample	9.31	4.20	1.43	85.06
Whole corn	Ear No. 1	**9.28**	**4.20**	**1.41**	**85.11**

*Obtained by direct separation from grits.

In general the composition of these mill separations agrees with the composition of the same parts separated by hand, although in nearly all cases the mill products show more or less contamination or mixture with other parts of the kernel. Thus the mill hulls are noticeably high in protein and oil owing to the presence of some particles of horny gluten and germ; while the mill germs are too low in protein and oil because of the presence of some hulls and tip caps. Furthermore, some oil is lost from the germ and absorbed by other parts in the milling process. The fine grits are almost pure horny starch, except that they contain about twice as much oil as the hand-separated product. This is doubtless due to the fact that some germs are broken or crushed in the hulling machine and the liberated oil is absorbed to some extent by the hominy, chiefly, of course, by the white starch, as indicated by the high oil content of the break flour and the other regularly separated corn flour, although it is evident that a small portion of this liberated oil remains adhering to the fine grits. The white starch contains 5.88 to 5.91 percent of protein, while the horny starch (fine grits) contains 8.46 percent, or almost one-half more.

It will be observed that the two samples of whole corn are almost identical in composition. While the corn is fairly representative of much of the white corn grown during the season of 1902, attention is called to the apparent fact that this is not the most suitable corn for the manufacture of hominy and grits. It seems evident that corn containing a higher percentage of the horny starchy part would be more valuable for the hominy mill. The manager of the American Hominy Company's Mills at Decatur has assured the writer that he prefers corn which shall run high in grits (horny starch), but he does not desire that the oil content should be increased; indeed, it would be much better for milling purposes to have the percentage of oil in corn reduced, because of the difficulty of preventing the oil from being absorbed by other products and injuring their quality, the tendency being for the oil to become rancid when exposed to the air. The hominy mills offer some encouragement to farmers to grow corn especially suited to their use.

SUMMARY OF BULLETIN No. 87.

The investigations reported in this bulletin serve to establish the following facts:

1. The kernel of corn consists of six readily observable and distinctly different physical parts, which are known as (1) the tip cap, (2) the hull (3) the horny gluten, (4) the horny starch, (5) the white starch, (6) the germ.

2. The tip cap covers the tip or base of the kernel and comprises only about 1.5 percent of the grain.

3. The hull is the very thin outer coat. It comprises about 6 percent

of the kernel and contains a lower percentage of protein (about 4 percent) than any other part of the kernel.

4. The horny glutenous part (aleurone layer) lies underneath the hull surrounding the kernel. It comprises from 8 to 14 percent of the grain (being more abundant in high protein corn), and it contains from 20 to 25 percent of protein, being the richest in protein of all the parts of the corn kernel.

5. The horny starchy part is the chief substance in the sides and back of the kernel (the germ face being considered the front of the kernel). This substance comprises about 45 percent of ordinary corn, but is much more abundant in high protein corn and less abundant in low protein. Although rich in starch it contains about 10 percent of protein (more in the high protein corn and less in low protein corn). It contains a greater total amount of protein than any other part of the kernel.

6. The white starchy part occupies the center of the crown end of the kernel and usually partially surrounds the germ. It comprises about 25 percent of the kernel (less in high protein corn and more in low protein corn). It is poor in protein (5 to 8 percent).

7. The germ occupies the central part of the kernel toward the tip end. It comprises about 11 per cent of the kernel (more in high oil corn and less in low oil corn). The germ contains from 35 to 40 percent of corn oil or from 80 to 85 percent of the total oil content of the corn kernel.

8. High protein corn contains a large proportion of the horny parts (both of the horny glutenous part and the horny starchy part), and a correspondingly smaller proportion of the white starchy part. The horny parts comprise more than 60 percent of high protein corn and contain about 80 percent of the total protein content of very high protein corn.

9. The value and reliability of the method proposed in previous bulletins by which any farmer can select high protein seed corn (selecting for a large proportion of horny parts) by a simple mechanical examination of the corn kernels has been fully confirmed by the results which have been subsequently obtained and which are now reported in this bulletin.

10. The value of the method proposed for picking out high oil seed corn by selecting for a large proportion of germ is also fully established.

11. The degree of correlation existing in the corn kernel between the percentages of germ and protein is very slight and is frequently entirely absent, consequently the proportion of germ in the corn kernel is not a reliable index of its protein content.

12. The composition of the different products obtained from corn by hominy mills, as well as by other factories, serves greatly to emphasize the importance of breeding corn for special purposes.

(For more complete details of corn breeding, the reader is referred to Bulletin No. 82, "Methods of Corn Breeding," which can be obtained upon

request from the Illinois Experiment Station, Urbana, Illinois. The supply of Bulletin No. 53 and Bulletin No. 55, both relating to corn investigations, is now exhausted.)